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Validation of piezoelectric measurement system for weapon firing pin percussion energy

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ABSTRACT

Functional reliability of a service firearm is essential. A failure to fire at a critical moment could lead to disastrous consequences. The firing pin of a weapon must hit the primer hard enough to ascertain reliable detonation of the primer which then ignites the powder. Depths of firing pin created indent on an inert primer and on a copper cylinder are the two methods conventionally used to estimate this percussion energy. In this study the copper cylinder method was compared with piezoelectric measurement. It was found out that both systems give reliable readings. Eight pistols of calibre 9 mm were measured. Although the majority of the measured weapons seemed to provide sufficient percussion energy, there were some surprisingly low readings with seemingly perfect weapons. This discrepancy shows the necessity of an industrial standard and of using a reliable percussion energy measurement system for monitoring the condition of service weapons. Further research on firearm and ammunition primer compatibility is required.

1. Introduction

A modern small-arms percussion primer contains a primer compound consisting mainly of impact sensitive initiator explosive, oxidizer and fuel. The ignition is caused by the weapon firing pin impacting the percussion primer. The impact compresses the explosive between the primer cup and anvil thus detonating the initiator. The resulting flame then ignites the powder. The firing pin must have sufficient kinetic energy to cause a deep indent on the primer cup.

NATO standards [1,2] are generally used by the ammunition manufacturers as a guideline on defining and measuring primer sensitivity. For 9 mm pistol primers they specify dropping a 55 g steel sphere on the firing pin requiring 100% fire at drop height of 305 mm (12 in.). The standards, however, do not define the mass of the firing pin, which is essential for defining the actual impact energy (percussion energy) of the firing pin. They, however, do define a firing pin diameter of 1.98 mm whereas the diameter used for instance by SIG-Sauer and Heckler and Koch pistols is 1.8–1.6 mm respectively [3]. Primer sensitivities are tested using different drop heights to obtain a sensitivity distribution, 50% ignition height (H) and standard deviation (S). The primer manufacturers ordinarily announce sensitivity as $H + 5S$ and $H - 2S$ values as "all fire" and "no fire" heights. The $H + 5S$ drop height is usually between 10 and 12 in.. These drop heights must, however, be expressed in resulting impact energies to be able to compare primer sensitivities with percussion energies of weapons.

International organizations Commission Internationale permanent Pour l'Epreuve des Armes à Feu portatives (CIP) and Sporting Arms and Ammunition Manufacturers' Institute (SAAMI) have standardized cartridge chamber and ammunition minimum and maximum dimensions as well as maximum chamber pressures. German police technical guideline [4] specifies measuring the percussion energy of a pistol with a cylinder of pure copper inserted into a measurement cartridge whose length corresponds to the maximum case length allowed by CIP and SAAMI

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Fig. 1. Measurement cartridge and copper crusher cylinder.

(Fig. 1). These copper cylinders are actually made for the crusher method measurement of chamber pressure. When measuring percussion energy, the intention is to press the copper cylinder tightly against the weapon breech face. The firing pin impact causes an indent on the copper cylinder (Fig. 2). The depth of the indent is then measured and the result used for estimating the sufficiency of the percussion energy of the weapon. The German technical guideline specifies the minimum indent depth as 0.3 mm. Mil-Std spec of 9 mm pistol [6] requires that the pistol shall produce 0.03–0.043 mm indent on a copper cylinder. Based on discussions with weapon manufacturers an indent of 0.26 mm is often used as a requirement.

National Institute of Justice [5] specifies a similar method. Instead of using a copper cylinder it recommends using a headspace gage modified to allow insertion of an unfired primer. This assembly is then used to verify the sufficiency of the percussion energy. The problem with this method is that the hardness of the unfired primers must be verified and thus the indent be calibrated. The system can neither be used to check the concentricity of the firing pin impact as the headspace gages are typically cylindrical instead of conical allowing the gage head to move slightly.

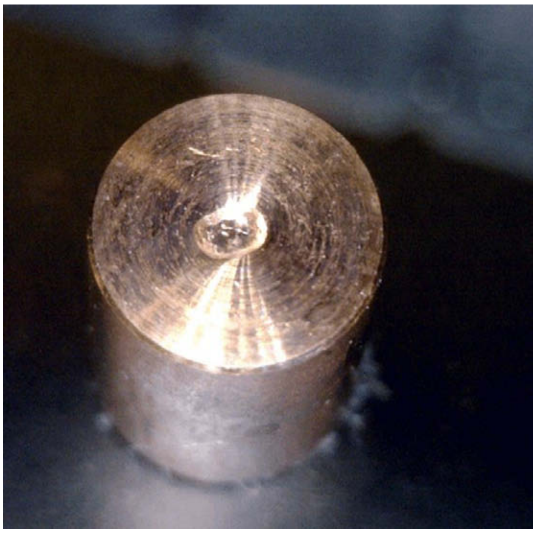

Fig. 2. Indent made by Glock-pistol firing pin on a copper cylinder head.

A percussion mechanism of a firearm consists in principle of a percussion spring, percussion mass ("hammer") and a firing pin. Firearms employ two major percussion mechanism modes. In single action mode the hammer is under spring tension resting on a retaining lever called sear. A pull on the trigger moves the sear releasing the hammer. It hits the firing pin which then strikes the primer. In double action mode pulling the trigger will first cock the hammer before releasing it. Usually the double action strike is slightly shorter producing less percussion energy than single action. All weapons do not use both modes.

Piezoelectricity is the ability of some materials to generate an electric field or electric potential in response to applied mechanical stress. This method is used in the Firing Impulse Tester (FIT), made by the Italian company STAS. The transducer assembly consists of an impact anvil against which the firing pin strikes, a pressure transducer and an elastic element in between. These components are assembled inside a stainless steel body with the external dimensions of a cartridge in each calibre to be measured. The assembly, later in the text referred to as the transducer, should therefore fit snugly into the cartridge chamber of a firearm.

Published scientific reports relevant to the issue of percussion primer sensitivity and shedding additional light on the subject of this study could not be found. The purpose of this study was to compare two measurement systems and to shed light to the problem of measuring percussion energy.

2. Materials and methods

In the copper cylinder method a special chamber gage of 19.14 mm length was used. The length is close to the maximum case length 19.15 mm of a 9 mm × 19 cartridge [7,8]. The difference can be considered negligible in this case. A cavity to hold a 6 mm copper crusher cylinder flush with the gage base had been milled in it. Crusher cylinders made by Wilhelm Handke GmbH were used. The depth of indent made by the impacting firing pin was measured using a digital gage on a measurement bench. Fig. 3 shows a similar arrangement used at the NBI Forensic Laboratory. The tip of the measurement head was placed in the centre of the indent and the gage was zeroed. The copper cylinder head height was then measured at four places around the indent and the mean value was used as the depth of the indent. This measurement method reduces the effect of possible imperfections of the cylinder head surface.

The piezoelectric system (Fig. 4) made by STAS was to some extent still on a prototype stage. For example, the gage did not fit in the chamber of a Glock 17 pistol.

Both systems were calibrated using a NATO specified drop test device [1,2] where a steel sphere weighing 55 g is dropped at specified heights onto a firing pin. To obtain

Fig. 3. Indent measurement setup.

Fig. 4. Piezoelectric STAS-system consisting of chamber inserted transducer and a control unit.

the impact energies the terminal velocity v_1 of the sphere was first calculated with Eq. (1).

$$v_1 = \sqrt{2ah} \tag{1}$$

In Eq. (1) a is the gravity constant 9.81 m/s^2 and h is the drop height in metres. The impact velocity v_{12} of the system consisting of the steel sphere and the firing pin is obtained from the following equation:

$$v_{12} = \frac{m_1 v_1}{m_1 + m_2} \tag{2}$$

In Eq. (2) m_1 is the mass of the sphere and m_2 the mass of the firing pin, both in kilograms. The latter was measured to be 7 g. The percussion energy E_p is therefore

$$E_p = \frac{1}{2}(m_1 + m_2)v_{12}^2 \tag{3}$$

Calibration measurements of the piezoelectric system were done using the drop test device at 12–3 in. heights with 3 in. intervals on copper cylinder and 1 in. interval with STAS to see the linearity of measurement response and to establish possible correction equations.

The pistols shown in Table 1 were measured with both copper crusher and STAS. All weapons were clean, serviced and in good condition. All pistols had the standard percussion spring. The weapons were fired in single action mode where applicable recognizing the fact that in general the first shot is fired double action producing slightly lower percussion energy due to shorter hammer travel. The pistols were held horizontal position.

Each measurement was carried out six times in normal office environment. Calculations were done using Microsoft Excel 2003 SP3.

3. Results

Theoretical percussion energies obtained with the steel sphere system are shown in Table 2. Calibration results obtained with a drop testing device are shown in Table 3 for copper cylinders and Table 4 for the piezotransducer. The copper cylinder indents show good linearity and small standard deviations indicating good measurement accuracy. The regression curve (Fig. 5) was derived with least square method. Linear curve gave very high correlation coefficient $R^2 = 0.9856$. Eq. (4) describes the relationship between the indent I and percussion energy E_p. A third degree polynomial gave an even better correlation of 0.993. Considering, however, the measurement uncertainty, the very small difference and the fact that the linear equation is easier to use and remember the linear equation is better for all practical purposes.

$$E_p = 0.7988 \times I - 0.0694 \tag{4}$$

The mean difference between steel sphere energies and STAS readings is −0.002 J which can be considered negligible. The STAS readings also show excellent linearity. As the difference is very small, no compensation equation is necessary to correct the readings.

Measurements of service pistols (Table 5) show marked differences between pistols. The number of pistols measured was too small to give any statistical confidence and to draw any conclusions concerning certain pistol types. According to NATO, the all fire height $H + 5S$ percussion energy is 0.146 J (Table 2). The Mil-std [6] requires the Cu

Table 1
Test weapons.

Weapon	Number
Heckler and Koch USP Compact	27049485
SIG-Sauer 226	U685831
SIG-Sauer 228	B236348
SIG-Sauer 229	AM71904
Glock 17	EZF868
Heckler and Koch P30L	300007
Heckler and Koch P30L	300008
Beretta 92FS	G005307

Table 2
Percussion energy E_p of a steel sphere system.

Drop height		v(sphere) (m/s)	v_p (m/s)	E_p (J)
in.	m			
12	0.305	2.445	2.169	0.146
11	0.279	2.341	2.077	0.134
10	0.254	2.232	1.980	0.122
9	0.229	2.118	1.879	0.109
8	0.203	1.997	1.771	0.097
7	0.178	1.868	1.657	0.085
6	0.152	1.729	1.534	0.073
5	0.127	1.579	1.400	0.061
4	0.102	1.412	1.252	0.049
3	0.076	1.223	1.085	0.036

indents to be between 0.3 and 0.42 mm. Converted to energy with Eq. (4) this means 0.17 and 0.27 J, respectively. Even with this small sample of pistols one can safely draw the conclusion that there is incompatibility between ammunition primer sensitivity and pistol percussion energy.

4. Discussion

The concept of using a copper cylinder has some basic problems. Firstly, controlling the hardness of copper cylinders may be difficult as manufacturing batches may be slightly different. Every new batch should therefore be calibrated with a drop tester and Eq. (4) adjusted accordingly. The copper cylinders are also originally intended for measurement of chamber pressures and their hardness relevant to a firing pin impact is not ordinarily announced. Secondly, different firing pin tip profiles and diameters may result in variation in indent depth. Indications of this are seen also in the test results. Instead of measuring only the depth the volume of the indent i.e. volume of the displaced copper should be measured. Thirdly, the indent and especially its volume are not easy to measure accurately. It is not easy to place the gage tip precisely in the deepest point of the indent. Fourthly, measuring the indents is a fairly slow and therefore costly method comparing to a piezoelectric method giving results in seconds.

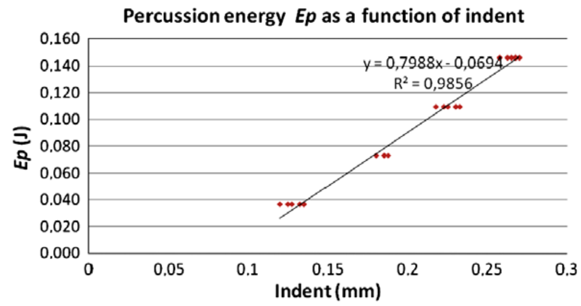

Fig. 5. Percussion energy to indent depth ratio on copper cylinders.

The documents specifying the copper cylinder method require the cylinder head to be tightly against the breech face of the weapon. In reality the primer of a cartridge is seated usually about 0.15 mm below the case head. Additional gap may be caused by cartridge case length being close to CIP and SAAMI specified minimum. The total gap between the breech face and the primer could therefore be closer to 0.25 mm. This gap could bear significance if the firing pin protrusion is too short or the pin rapidly slows down due to insufficient energy or excessive friction. In principle the gap should be taken into consideration when measuring percussion energies. The thickness of the primer compound in a small pistol primer is approximately 0.4 mm. A firing pin protrudes usually about 1–1.5 mm from the weapon breech face. If it has enough kinetic energy, the protrusion should be sufficient for reliable ignition of the primer. Therefore it seems safe to assume that this dimensional discrepancy is irrelevant.

Table 3
Indents on a copper cylinder.

Drop height		E_p (J)	Cu-cylinder indent measurements (mm)							
in.	m		1	2	3	4	5	6	Mean	S
12	0.305	0.146	0.263	0.265	0.268	0.268	0.258	0.270	0.265	0.004
9	0.229	0.109	0.230	0.230	0.218	0.223	0.233	0.225	0.226	0.006
6	0.152	0.073	0.180	0.185	0.185	0.185	0.188	0.180	0.184	0.003
3	0.076	0.036	0.135	0.135	0.120	0.133	0.128	0.125	0.129	0.006

Table 4
STAS FIT percussion energy measurements.

Drop height		E_p (J)	STAS FIT percussion energy measurements (J)								Error (J)
in.	m		1	2	3	4	5	6	Mean	S	
12	0.305	0.146	0.143	0.145	0.146	0.146	0.145	0.145	0.145	0.001	0.001
11	0.279	0.134	0.133	0.134	0.133	0.133	0.134	0.134	0.134	0.001	0.000
10	0.254	0.122	0.120	0.122	0.122	0.122	0.121	0.122	0.122	0.001	0.000
9	0.229	0.109	0.112	0.112	0.111	0.111	0.111	0.111	0.111	0.001	−0.002
8	0.203	0.097	0.101	0.101	0.100	0.100	0.099	0.100	0.100	0.001	−0.003
7	0.178	0.085	0.089	0.088	0.087	0.088	0.088	0.087	0.088	0.001	−0.003
6	0.152	0.073	0.076	0.077	0.076	0.077	0.076	0.077	0.077	0.001	−0.004
5	0.127	0.061	0.064	0.064	0.064	0.064	0.065	0.065	0.064	0.001	−0.004
4	0.102	0.049	0.052	0.053	0.052	0.052	0.053	0.052	0.052	0.001	−0.004
3	0.076	0.036	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.000	−0.002
									Mean error		−0.002

Table 5
Pistol percussion energies.

Pistol	S/N	Method	Percussion energy measurements (J)							
			1	2	3	4	5	6	Mean	S
Beretta 92FS	G005307	Cu (mm)	0.328	0.323	0.323	0.328	0.333	0.333	0.328	0.004
		Ep(Cu)	0.193	0.189	0.189	0.193	0.197	0.197	0.193	0.004
		Ep(STAS)	0.230	0.240	0.250	0.250	0.250	0.230	0.242	0.010
		Diff. (J)	−0.037	−0.051	−0.061	−0.057	−0.053	−0.033	−0.049	0.011
Glock 17(see note 1 below)	EZF868	Cu (mm)	0.318	0.338	0.310	0.355	0.343	0.340	0.334	0.017
		Ep(Cu)	0.185	0.201	0.179	0.215	0.205	0.203	0.198	0.013
		Ep(STAS)								
		Diff. (J)								
H and K P30L	300007	Cu (mm)	0.285	0.290	0.288	0.295	0.293	0.303	0.292	0.006
		Ep(Cu)	0.159	0.163	0.161	0.167	0.165	0.173	0.164	0.005
		Ep(STAS)	0.190	0.180	0.180	0.190	0.180	0.170	0.182	0.008
		Diff. (J)	−0.031	−0.017	−0.019	−0.023	−0.015	0.003	−0.017	0.011
H and K P30L	300008	Cu (mm)	0.313	0.305	0.305	0.323	0.315	0.325	0.314	0.008
		Ep(Cu)	0.181	0.175	0.175	0.189	0.183	0.191	0.182	0.007
		Ep(STAS)	0.217	0.203	0.196	0.170	0.202	0.168	0.193	0.020
		Diff. (J)	−0.036	−0.028	−0.021	0.019	−0.019	0.023	−0.011	0.025
H and K USP compact	27049485	Cu (mm)	0.305	0.305	0.305	0.313	0.308	0.305	0.307	0.003
		Ep(Cu)	0.175	0.175	0.175	0.181	0.177	0.175	0.176	0.002
		Ep(STAS)	0.160	0.160	0.160	0.160	0.160	0.160	0.160	0.000
		Diff. (J)	0.015	0.015	0.015	0.021	0.017	0.015	0.016	0.002
SIG 226(note 2)	U685831	Cu (mm)	0.253	0.268	0.258	0.250	0.253	0.278	0.260	0.011
		Ep(Cu)	**0.133**	**0.145**	**0.137**	**0.131**	**0.133**	0.153	**0.138**	0.009
		Ep(STAS)	**0.120**	**0.130**	**0.120**	**0.130**	**0.120**	**0.130**	**0.125**	0.005
		Diff. (J)	0.013	0.015	0.017	0.001	0.013	0.023	0.013	0.007
SIG 228(Note 2)	B236348	Cu (mm)	0.250	0.280	0.270	0.260	0.260	0.290	0.268	0.015
		Ep(Cu)	**0.131**	0.155	0.147	**0.139**	**0.139**	0.163	**0.145**	0.012
		Ep(STAS)	**0.140**	0.170	0.160	0.170	0.160	0.170	0.162	0.012
		Diff. (J)	−0.010	−0.015	−0.013	−0.031	−0.021	−0.007	−0.016	0.009
SIG 229	AM71904	Cu (mm)	0.273	0.283	0.280	0.280	0.298	0.275	0.281	0.009
		Ep(Cu)	0.149	0.157	0.155	0.155	0.169	0.151	0.156	0.007
		Ep(STAS)	0.170	0.160	0.160	0.170	0.170	0.170	0.167	0.005
		Diff. (J)	−0.021	−0.003	−0.005	−0.015	−0.001	−0.019	−0.011	0.009

Mean difference between Cu and STAS readings (J) −0011.
Note 1: Transducer did not fit in the Glock cartridge chamber.
Note 2: Mean percussion energy is below the NATO 12 in. drop height energy of 0146 J.

It can therefore be said that the copper cylinder method serves only as a rough indication of possible problems. The piezoelectric method seems to overcome above problems by providing a consistent reusable measurement tool. It also gives far more information on the percussion event thus opening more ways to research it. At present the piezotransducer has a problem. It did not fit in the Glock chamber. The transducer is made to CIP minimum cartridge dimensions and the Glock appears to have minimum chamber dimensions. The transducer cannot be made much smaller without losing the concentricity with the chamber axis and subsequently some of the measurement precision.

Further studies on percussion primer detonation is required to find out how firing pin impact energy, impact velocity, tip diameter and tip profile affect primer detonation. Do these variables change detonation timing and output? Without precise test data comparing primer reliability and sensitivity against percussion energy can only be regarded as an approximation.

There seems to be a rather serious incompatibility between weapon percussion energy and primer sensitivity due to lack of standardization. Considering the use of a pistol in self defence a failure to fire at a critical moment could lead not only to discussion on liability but also to fatal consequences. In a critical situation the first shot is often decisive. Depending on the weapon construction the first shot is also often fired in double action mode giving less percussion energy than the subsequent single action shots.

Most frequently, however, the problem of a misfire is connected to the question of ammunition quality. With no definitions and contractual agreements of compatibility the ammunition manufacturer blames the weapon and vice versa. This could lead to arguments on who is to pay for the delivery of millions of rounds of ammunition.

It is therefore proposed that

1) ammunition manufacturers must announce the $H + 5S$ value in joules,
2) firearm manufacturers must announce the minimum percussion energy of their product
3) weapon users insist and control that the service weapons produce at least 5% higher percussion energy than the corresponding $H + 5S$ energy of the ammunition they use and

4) an international standard is published on measuring the percussion energies and primer sensitivities.

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